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SHUTTLE IMPACT ON COMMUNICATIONS SATELLITES AS SEEN FROM THE US--ETC(U)

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Shuttle Impact on Communications Satellites As Seen from the User Viewpoint

See 1473

FLTSATCOM Program Office
Satellite Systems Division
Systems Engineering Operations

October 1977

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Prepared for

SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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IUS	Upper Stages

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The impact of the Space Transportation System (STS) on communication satellites during and beyond the transition period for civilian and military projects is examined. The 15-ft diameter by 60-ft long shuttle cargo bay, its 65,000-lb east launch payload capability, and use of either solid spinning perigee kick systems or the interim upper stage (IUS) constitute the elements that may permit economical use of the STS by payload sharing of the cargo bay. A measure of spacecraft growth in weight and capability plus changes in configuration for STS adaptation can be expected. Profitable cargo bay length utilization and mixed

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19. KEY WORDS (Continued)

20. ABSTRACT (Continued)

cont

payload integration planning will be some of the most important issues to be resolved.

CONTENTS

FIGURES

FIGURES (Continued)

I. INTRODUCTION

The advent of the Space Transportation System (STS), namely the shuttle plus upper stage concepts, by virtue of its unique features and capabilities, will mark the beginning of a new era in the manner of orbiting payloads.

To understand the uniqueness of the STS, we must first take a look at the present way of emplacing communications satellites with the three conventional launchers shown in Fig. 1. Their range of capability in terms of useful weight in synchronous equatorial orbit is between 730 and 3, 380 lb, with fairing diameters ranging between 8 and 10 ft.

By contrast, and it is a startling contrast, the shuttle, which is a reusable rocket vehicle with jettisonable propulsion assist and which features a cargo bay measuring 60 ft in length and 15 ft in diameter, can place payloads and mission-peculiar equipments weighing up to 65, 000 lb in a 160-nmi circular orbit for a due east launch out of ETR. Communications satellites will be deployed in low earth orbit and propelled to final orbit either by a solid propellant interim upper stage (IUS) with a maximum synchronous equatorial capacity of 5, 000 lb or a solid spinning upper stage (SSUS)/apogee kick motor (AKM) combination with a maximum capability about half that of the IUS.

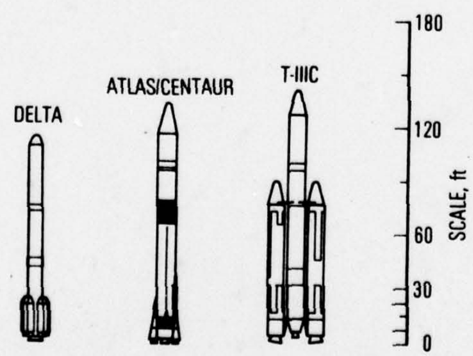

Fig. 1. U.S. Satellite Launch Vehicles - Typical Models

The objective of this paper is to assess the impact on communications satellites of the transition from expendable dedicated boosters to a reusable launcher. The large cargo bay of the reusable launcher offers higher payload capability with quasi-aircraft transportation to orbit and the possibility of cargo sharing. Boost into final orbit will still be by dedicated expendable means.

II. TRANSITION PERIOD

Although it is the express objective of the STS to be the sole national launch vehicle system, it appears unreasonable to immediately phase out the Delta 2914/3914, Atlas/Centaur, and Titan IIIC expendable boosters when the shuttle reaches operational status. For a certain period of time, the new and old launch systems will serve side by side, complementing each other during the transition period. Missions during this period will be designed to be compatible with their expendable launcher and the shuttle/dedicated upper stage: Intelsat V comes to mind in the civilian sector, and DSCS III for the DoD.

The exact duration of the transition period is difficult to determine because of many unknown factors; e.g., the availability of shuttles at the beginning of the operational period, and the availability of spacecraft for shared cargo bay transportation into low earth orbit. The transition period will probably be different for military and civilian spacecraft. To this effect, the Air Force is designing the IUS to be compatible with the Titan III vehicle in lieu of the transtage. This assures availability of a backup launch system for payloads designed to fly onboard the IUS.

III. COMSATS, CIVILIAN AND MILITARY

The differing requirements, and thus design aspects of civilian and military communications satellites must be taken into account in this assessment.

Military satellites typically incorporate a number of unique safeguards and security provisions such as command security; secure voice and antijam of security links; radiation hardening; and, in many cases, additional operational flexibility and diversity to accommodate different user organizations. Implementation of these requirements requires increased weight, power, and complexity; we therefore conclude that the military COMSAT is and probably will be heavier, larger, and more complex than its "equivalent" civilian counterpart.

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IV. CAPABILITIES/COST, PRESENT AND FUTURE

Up to now, COMSAT design was dictated by the capability, cost, and fairing diameters of available launchers; fairing length was generally adequate and did not impose any significant design constraint. Consequently, three distinct levels of weight/diameter combinations governed COMSAT configurations:

Launch Vehicle	Available Max On-Orbit Wt, lb	Fairing Dia, ft	Responsible Agency
Delta 2914/ 3914*	≈800/1,000	8	NASA
Atlas/Centaur	≈2,000	10	NASA
Titan IIIC	≈3,400	10	DoD

The following costs, which ignore some of the fiscal complexities due to inflation, production rate, and different costs charged to government and non-government users, are adopted as an "average relative yardstick." Absolute differences would have no significant impact on this overall assessment:

Launch Vehicle	Cost, $M
Delta	15
Atlas/Centaur	25
Titan IIIC	35

*3914 is a commercial vehicle.

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V. UPPER STAGES

It appears that three upper stages will be available, without which shuttle payloads will be restricted to low earth orbits. The main effort will be concentrated on the USAF *IUS*, *which consists of* a jettisonable perigee solid rocket motor (SRM) and an apogee SRM. The stage has inertial guidance, is three-axis stabilized, and is designed with high reliability in mind. It is expected to have a capability of 5,000 lb in synchronous equatorial orbit. Pertinent IUS characteristics are (as presently envisioned):

Weight	32,600 lb
Diameter	9.5 ft
Length	16.5 ft

The other two propulsive devices are solid spinning upper stages (SSUSs), which provide the perigee burn into synchronous transfer orbit and which will be privately developed with NASA agreement. These stages are essentially perigee kick motors with the requisite ancillary equipment. The apogee burn will be provided by the satellite AKM, ignited at the appropriate time by ground command. This procedure is common practice (e.g., the Intelsat series). The SSUS-A (Fig. 2) will be sized for Atlas/Centaur-class payloads, and the SSUS-D (Fig. 3) will be sized for Delta-class payloads.

Although the SSUS concept is presently tied to the transition period expendable *booster* payload *classes, there is no reason why it cannot be adapted* to shuttle-designed payloads later; the concept remains viable. Potential SSUS characteristics are (as presently envisioned):

	SSUS-A	SSUS-D
Weight	7,800 lb	3.960 lb
Diameter	5.1 ft	4.5 ft
Length	6.2 ft	6.1 ft

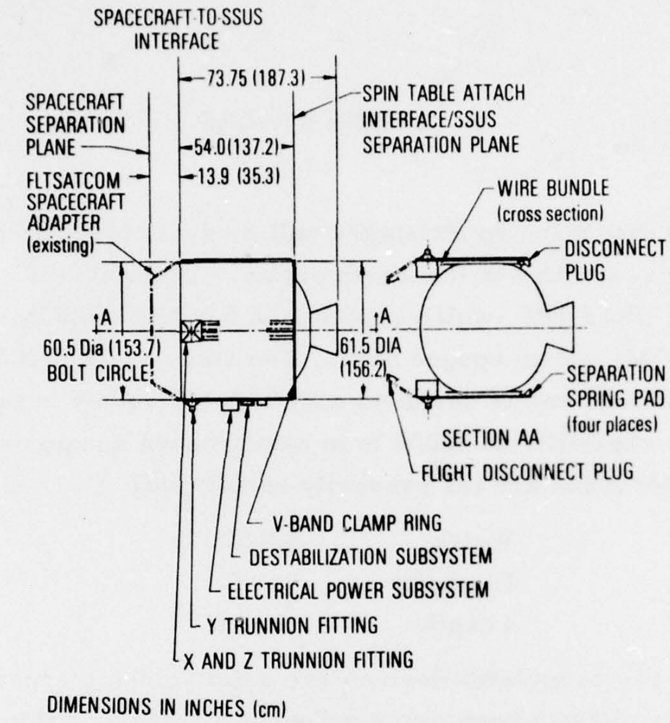

Fig. 2. SSUS-A Stage Configuration

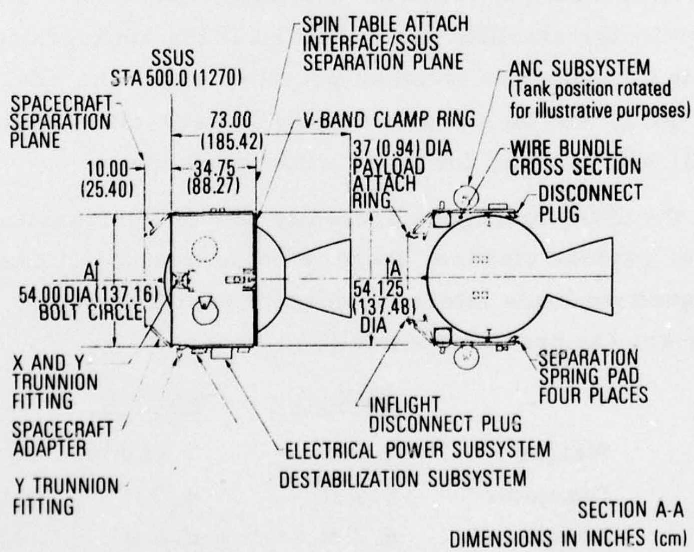

Fig. 3. SSUS-D Stage Configuration

VI. COST

The NASA pricing policy for standard shuttle launches from ETR will probably be (in 1975 dollars):

$20.9 M for non-DoD
$12.2 M for DoD

Present DoD thinking is to avoid mixing of civilian and military payloads by "chartering" an entire shuttle and apportioning the cargo bay to a number of users. The manner in which this will take place has not yet been determined.

On the other hand, the NASA cost policy for shared flights has been established. The shared cost is based on a charge factor, which in turn is derived by the larger of the length or weight fraction required by a specified payload divided by 0.75. The total transportation cost is determined by multiplying the charge factor by the total flight cost of a shuttle (Fig. 4). Additionally, estimates of first-time integration costs will amount to approximately $8 M for a single payload and $11 M for two plus $1.0 M recurring, including launch support per payload. Estimates of upper stage costs are:

Stage	Cost, $ M
IUS (DoD)	≈6.0*
SSUS-A	3.0**
SSUS-D	2.0**

*Approximate present estimate in 1977 dollars for production phase beginning in 1982 (excludes launch cost).

**Includes amortization of RDT&E costs, 1975 dollars.

$$\text{PRICE} = C_f \times \text{DEDICATED PRICE}$$

$$\text{LOAD FACTOR} = \begin{Bmatrix} \dfrac{\text{PAYLOAD WEIGHT, lb}}{\text{SHUTTLE CAPABILITY}} \\[2ex] \dfrac{\text{PAYLOAD LENGTH, ft}}{60} \end{Bmatrix} \text{ WHICHEVER IS GREATER}$$

SHUTTLE CAPABILITY	
INCLINATION, deg	WEIGHT, lb x 10^{-3}
28.5	65
56	57
90	37
104	30

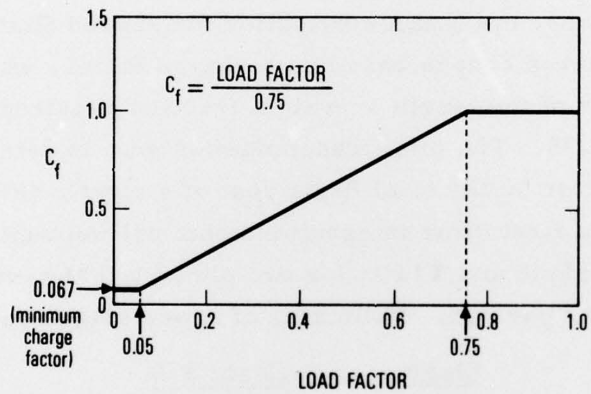

Fig. 4. Determination of Charge Factor (C_f) for 160 nmi

VII. IMPACT ON COMSATS

How will the STS affect the design of COMSATS? One major potential impact certainly is the removal of weight boundaries traditionally imposed by expendable launchers. Satellites could grow to 5,000 lb from the 3,400-lb ceiling established by Titan IIIC. The weight limits, namely 1,000 and 2,000 lb, fixed by the Delta and Atlas/Centaur boosters, respectively, vanish. Consequently, the designer will have the freedom to meet requirements with additional design flexibility and without rigid weight ceilings.

The trend toward increased COMSAT weight (Fig. 5) clearly shows that the maximum payload capability of the boosters is reached in due time. Titan IIIC (single launch) is an exception to this rule; its capability of 3,400 lb has not once been attained.

The question now arises: How can the additional weight capability of the STS be used to good advantage? Experience has shown that weight increases with time and with each succeeding version and generation of COMSATs. The rate of growth so far has not been dramatic; nevertheless, a more generous weight allocation offers the prospect of:

- Increased communication capacity
- Increased on-orbit time
- Increased on-orbit propulsive capability (fuel)
- Increased power
- Increased redundancy and reliability
- Larger antenna systems
- Increased security implementation for DoD COMSATs

One very practical aspect of the absence of a rigid weight limitation is the ability to absorb the weight growth that inevitably accompanies a maturing spacecraft development program, thereby precluding costly redesign, complex manufacturing processes, and schedule slippage.

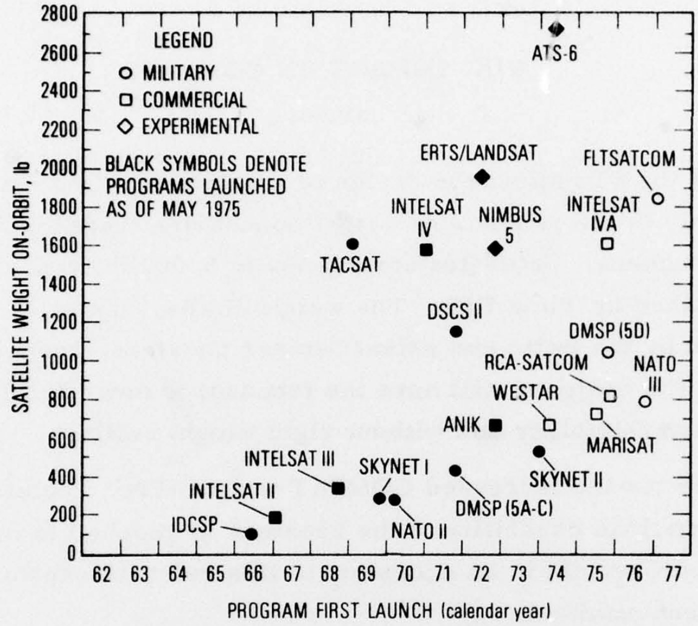

Fig. 5. Satellite Weight History (On-Orbit)

The possibility cannot be excluded that the STS 5,000-lb synchronous equatorial capability will eventually be matched by multipurpose COMSATs featuring large antenna systems, high power capacity, and longer on-orbit lifetimes; in other words, with much of the extra weight being absorbed by a highly versatile spacecraft bus. However, when considering large communication satellites, the high cost and complexity of the payload will remain very potent factors in determining the desirability of such a system.

Because of its volume and payload characteristics, the shuttle would lend itself ideally to multiple/mixed payloads (COMSATS plus upper stages). Theoretically, maximum filling of the cargo bay results in the lowest cost for each user sharing the flight. This would be especially true for civilian payloads because the transportation cost policy is clearly delineated by NASA. This policy will undoubtedly influence spacecraft design, placing a premium on payload length.

An effective length-saving method would be to install payloads (including upper stages) vertically rather than horizontally; the combination must be less than 15 ft long. Integration and scheduling problems remain, and the savings in length may be of questionable value for mixed payloads.

Another advantageous packaging concept would be clustering two COMSATs in tandem with an IUS. The satellites could weigh close to 2,500 lb each. Length would be utilized advantageously due to a single upper stage. The cost would also be advantageous, particularly for DoD and other government users.

The cost, planning, and scheduling aspects of payload integration will have a significant impact on mixing payloads to make maximum use of the weight/volume/cost characteristics of the shuttle. Multiple payload integration constitutes but a more complicated version of a single payload because of identical mission requirements, mass properties, propulsive units, and program control; however, none of these advantages apply to mixed payloads. Integration of mixed payload combinations must be planned years before their expected launch dates. Furthermore, contingencies will have to be worked on for no-show of one of the payloads and possible replacement by acceptable alternate payloads. Consequently, to take advantage of the shuttle, extensive planning must be performed to establish acceptable partnerships, with a resulting loss of launch flexibility. Launch availability and scheduling will dictate satellite launch rather than the other way around; however, painstaking planning can reduce the waiting period before launch.

An interesting solution to the complex design and programmatic aspects of integration would be to design COMSATs in a modular manner. The spacecraft and payload modules, conforming to known mass property and dynamic characteristics, would permit mixed integration, and thus efficient shuttle utilization. Subsystems will also "clip in" in a modular manner; in other words, a standardized "pallet" approach.

VIII. EXAMPLES

Examples of a number of conceptual integration approaches with the shuttle are provided for one (DoD) payload in the Atlas/Centaur class (FLTSATCOM) and for several other (commercial) satellites in the Delta class. These concepts were generated in the course of an SSUS feasibility study conducted by The Aerospace Corporation for NASA.[1]

The FLTSATCOM spacecraft, which at the time of the study substituted for Intelsat V (Fig. 6), used an SSUS for boost into the transfer orbit. This maintains the operational environment in the transfer orbit/apogee injection phases of the previous FLTSATCOMs launched on Atlas/Centaurs and minimizes design and operational changes. This combination weighs approximately 11,900 lb and measures about 275 in. in length, leaving 408 in. in the shuttle cargo bay. SSUS details are provided in Figs. 7 and 8, and dual FLTSATCOM launch is depicted in Fig. 9. It should be added that a FLTSATCOM minus its 2,050-lb AKM and some spinning attitude control electronics could also be placed in final orbit by an IUS, although it is oversized for such a mission. As a matter of fact, two FLTSATCOMs could be injected into their mission orbits provided they could be clustered in tandem, which is unlikely due to the spacecraft's antenna configuration.

Similar integration approaches were adopted in conjunction with an appropriately smaller SSUS for the two Delta-class commercial satellites shown in Fig. 10 (RCA/SATCOM and Hughes/MARISAT). Pertinent weights and dimensions are given in Figs. 11 and 12.

It can be seen that dual integration takes up less than half the cargo bay length (Fig. 13). Theoretically, four identical or two mixed pairs could be launched with one shuttle, provided that integration arrangements were made in a timely manner (Fig. 14).

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[1] Spinning Solid Upper Stage for Delta and Atlas/Centaur Class Missions (Study 2-6), ATR-76(7377-01)-1, The Aerospace Corp., El Segundo, Calif. (30 November 1976).

	FLTSATCOM
MASS, lb	4150
CG, in.	42
DIA, in.	109
LENGTH, in.	200
SPIN RATE, rpm	60

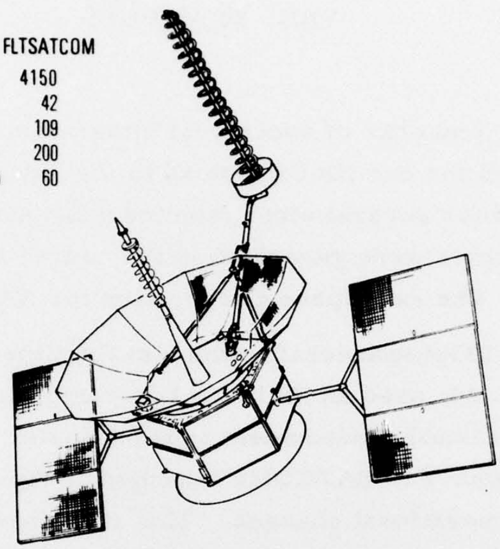


Fig. 6. FLTSATCOM and Intelsat V Characteristics

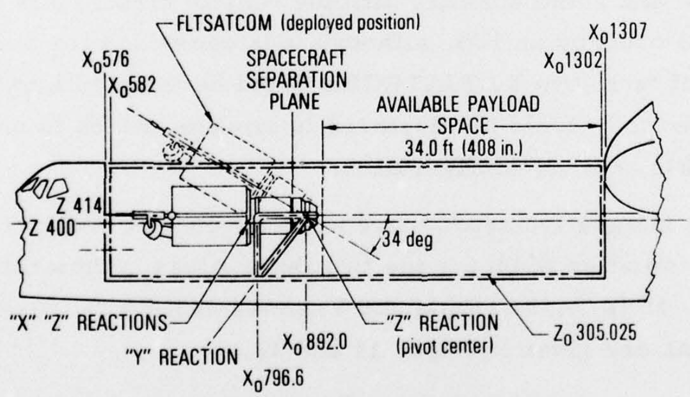
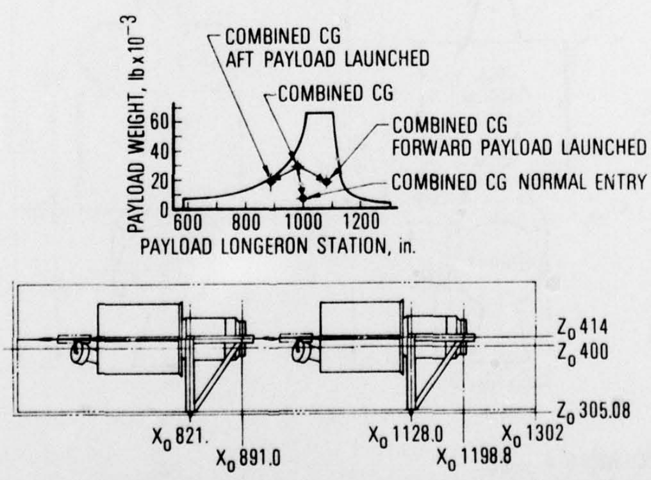


Fig. 7. Orbiter Payload Arrangement (SSUS/FLTSATCOM Spacecraft)

ITEM		IUS TECH SRM WEIGHT, lb
STRUCTURE		254
ELECTRICAL		30
BALLAST		10
DESTABILIZATION (Y_0)		10
THERMAL		5
ACTIVE NUTATION CONTROL*		35
CONTINGENCY		30
MOTOR (SRM)		7404
INERT	518	
PROPELLANT	6886	
SSUS		7778
FLTSATCOM SAT		4121
FLTSATCOM	4078	
ADAPTER	43	
LAUNCH WEIGHT		11899
LESS MOTOR WP		-6886
BURNOUT WEIGHT		4964
EJECT FLTSATCOM		-4078
SSUS JETTISON WEIGHT		886

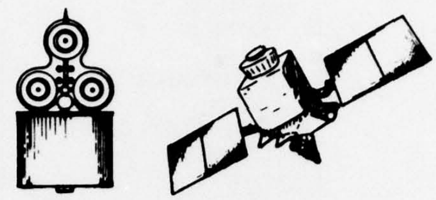
*Equivalent ballast used should system not be required

Fig. 8. FLTSATCOM/SSUS Weight Summary



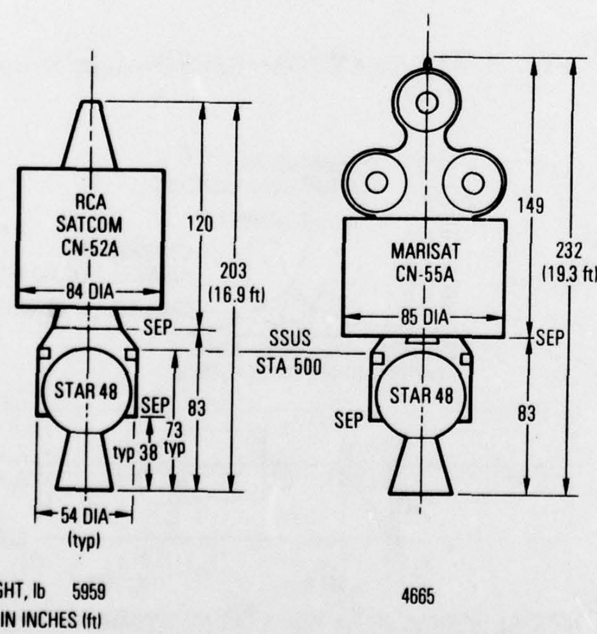
NOTE: ALL LONGERON ATTACH POINTS CAN ACCOMODATE DEPLOYMENT MECHANISMS FOR JETTISONING PAYLOAD AND CRADLE

Fig. 9. Dual Payload Combinations



CONTRACTOR/CUSTOMER	HUGHES/COMSAT	RCA/RCA
CLASSIFICATION/HISTORY	CN55A/1st LAUNCH 75	CN52A/1st LAUNCH 75
BASIC PROPULSION CAPABILITY	FW-5	SVM-7
DIMENSIONS - HEIGHT, ft (m)	12.5 (3.8)	4.5 (1.4)
WIDTH - ASCENT/DEPLOYED, ft (m)	7/7(2.1/2.1) (DIA)	6/31.4 (1.8/9.6)
MASS PROPERTIES		
WEIGHT, lb(kg) - LIFTOFF/ON-ORBIT	1446/727(656/330)	2000/1017(907/461)
MOI, slug-ft² (kg-m²) - $I_x/I_y/I_z$	270/270/124(366/366/168)	244/244/176(331/331/239)-
INTERFACES - STAGE	DELTA	DELTA 3914
LOADING, Gs - AXIAL/ LATERAL	18.0/1.0 (MECO/POGO)	18.0/1.0 (MECO/POGO)
SPIN RATE, rpm	100 (FULL SPINNER)	60 (3-AXIS ON-ORBIT)

Fig. 10. Basic Characteristics of Pathfinder Spacecraft (MARISAT and SATCOM)



LAUNCH WEIGHT, lb 5959 4665
DIMENSIONS IN INCHES (ft)

Fig. 11. SSUS/Spacecraft Vehicle Arrangements

ITEM	SATCOM (RCA)		MARISAT (Huges)	
SATELLITE		2000		1446
SSUS		3959		3219
STRUCTURE	230		230	
ELECTRICAL	30		30	
ACTIVE NUTATION CONTROL	35		35	
DESTABILIZATION	10		10	
THERMAL	5		5	
SPIN BALANCE	10		10	
CONTINGENCY	39		39	
MOTOR				
Wp	3409		2669	
INERT	191		191	
LAUNCH WEIGHT, lb		5959		4665

Growth allowance included over current spacecraft weight for maximum Delta-class payload SSUS design.

Fig. 12. SSUS/Spacecraft Weight Summary - Delta-Class Payloads

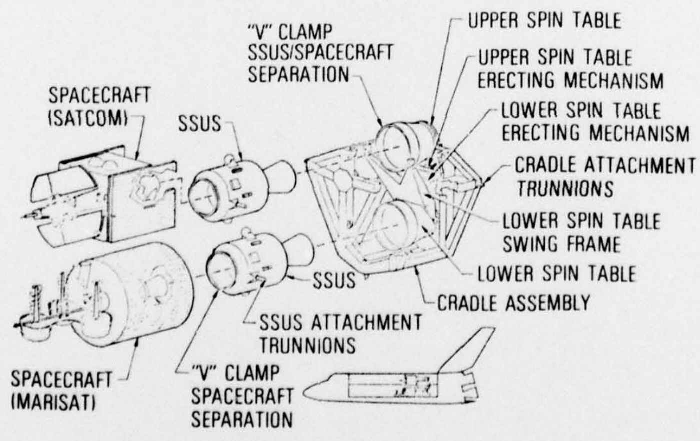


Fig. 13. SSUS/Spacecraft System - Dual Delta-Class Payloads (SSUS-D)

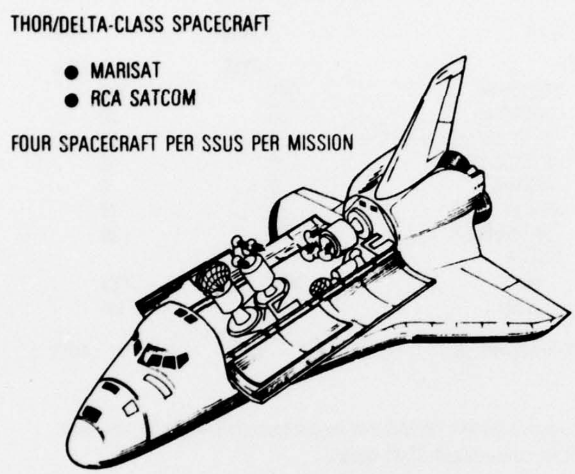


Fig. 14. Multiple Payload Candidates

IX. SUMMARY

What will be the expected STS impact on COMSATs? First let us reiterate the main issues that will influence the answers to this question:

Transition Period:

- Expendable launches and STS co-exist
- Transitional COMSAT design

Civilian and DoD COMSATs:

- Divergent mission requirements, design characteristics, and launch demand

Space Transportation System:

- Shuttle payload capability
- Orbiter cargo bay dimensions
- Integration of multi- and mixed payloads
- Upper stages: IUS and SSUSs
- Cost: NASA/civilian and DoD

No significant changes in COMSAT design can be anticipated during the transition period, i.e., to satellites designed to operate initially on expendable boosters and then on the STS. Examples are Intelsat V and DSCS III, which are merely adapted to the STS. DSCS III, an upgraded version of the DoD DSCS II satellite with more capacity and on-orbit life, faces the design challenge of compatibility initially with Titan IIIC, and then with the STS and Titan/IUS as backup. Design concepts are being evaluated, and it remains to be seen whether one design or a modular design can satisfy these varied requirements.

It can be expected that DoD COMSATs will be heavier than their civilian counterparts due to security, hardening requirements, and extended orbital repositioning capability.

The high payload capability of the shuttle removes, within reasonable limits, the weight ceiling on COMSAT design. This translates to a maximum

single payload of 5,000 lb in synchronous equatorial orbit via IUS delivery. COMSAT weight growth can be expected (possibly less in the payload than in the spacecraft module). Prospects offer larger antennas, more on-orbit lifetime/propellants, and additional redundancy, but explosive growth is not expected because it may not be necessary. Let us not forget that weight is directly a function of cost and that the old adage of dollar per pound of spacecraft will be just as valid in the STS era. One of the main assets of more available weight will be the ability to design and develop a spacecraft and, if necessary, make modifications without costly redesign. Therefore, a degree of design/development flexibility will be permissible.

The shuttle orbiter cargo bay will be filled by multiple and mixed payloads to take advantage of cost sharing. Civilian/commercial payloads will be charged according to their own cargo bay length or shuttle weight capability fraction. Length is expected to be the more critical cost factor, but only if multiple and, in particular, mixed payloads can be paired for integration far ahead of time. The resulting launch cost savings imply a compromise, i.e., a longer waiting period until launch. Since cost is a particularly critical factor for commercial COMSATs, length savings will result in shorter and wider configurations and in vertical placement in the cargo bay.

For a large number of spacecraft, the perigee kick motor (PKM)/SSUS concept as part of the overall spacecraft system, with either a solid or liquid propellant apogee injection system, appears attractive from the standpoint of cost and length savings. A number of SRM perigee modules will be available that will be able to meet the ΔV requirements of the weight range of COMSATs to be boosted out of low earth orbit with offloading, varying nozzle expansion ratios, and energy management.

It must again be emphasized that the lowest possible transportation costs hinge on multiple/mixed payloads, and consequently on shared costs. Such savings can only be realized by carefully planned integration of more than one payload. Otherwise, other efforts to configure satellites for flatness with

PKM/SSUS systems will be voided. Planning should concentrate on standardizing COMSATs within a range of modular concepts to facilitate integration and take full advantage of STS characteristics.

The same conclusions apply to DoD COMSATs, but with a lesser degree of emphasis on length because stringent mixing may be more complex and difficult due to the necessities of the military mission and the possibility of launch on demand. But here too the crux of efficient DoD shuttle utilization is careful integration: "planned partnerships." Furthermore, it is expected that the DoD COMSATs will make more frequent use of the IUS in single and dual launches than of PKM systems.

Finally, the STS will have all the elements for efficient and cost effective launching of satellite communications systems, provided that we adapt to the new launch system era and learn to master it to our advantage.